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Winter soil microclimate altered by corn residue management in the northern Corn Belt of the USA

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Abstract

Management of crop residue is important for promoting soil water recharge and early spring thaw in the northern Corn Belt of the USA. This study assessed the impact of residue management in no tillage, continuous corn (*Zea mays* L.) production systems on the soil thermal and water regime during winter in west central Minnesota. Residue treatments were initiated in the fall over three years and included the removal of stubble and loose residue (RR) from the soil surface, all residue lying prostrate (PR) on the soil surface, and stubble standing and loose residue lying (SR) on the soil surface. Soil (to 0.3 m depth) temperatures were recorded hourly whereas soil water content, frost depth, and snow cover were measured weekly. The SR treatment effectively trapped more snow, which resulted in warmer soil (2°C or less), shallower frost penetration (as much as 0.5 m), and earlier soil thaw (up to 20 d) as compared with the RR or PR treatments. Winter soil temperatures and depth and duration of soil freezing were the same for the RR and PR treatments. Soil water content was the same for all treatments prior to fall freezing, but was less for the PR treatment than for the SR or RR treatment during winter due to less snowmelt infiltration for the PR treatment. Corn production utilizing no tillage in the northern USA necessitates the retention of stubble on the soil surface for promoting warmer soil during the winter as well as earlier spring thaw as compared with removing or chopping stubble.

Keywords: Soil temperature; Soil water; Soil frost; Soil thaw

1. Introduction

Agricultural soils in northern climatic regions are subject to annual freeze-thaw cycles that affect physical properties of soils (Domby and Kohnke, 1955; Benoit, 1973). Soil physical properties altered during winter depend in part on the duration and magnitude of sub-freezing temperatures, number of freeze-thaw cycles, and the physical state of the soil at the time of freezing (Slater and Hopp, 1949; Willis et al., 1961; Leo, 1963; Benoit and Bornstein, 1970). For example, changes in soil aggregate stability and hydraulic conductivity induced by freezing are dependent on soil water content at the time of freezing, soil density, sub-freezing temperature, and rate of freezing (Gardner, 1945; Sillanpaa and Webber, 1961; Benoit, 1973; Kane and Stein, 1983; Mostaghimi et al., 1988)

Tillage and crop residue management can influence the occurrence and depth of soil freezing, especially in regions where wind is likely to redistribute snow. Management practices that aid in trapping snow will

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reduce the penetration of frost in the soil profile, particularly, if snow accumulation occurs early in the year (Chepil, 1954; Willis et al., 1961; Benoit et al., 1986). Benoit et al. (1986) found that tillage management influenced snow cover and winter soil temperatures in the northern USA. They suggested that soil warming can be enhanced in the spring by using management practices that minimize fall tillage or retain more residue on the soil surface in the fall. Little information is available, however, concerning the impact of residue management on the soil thermal and water regime during winter for corn production systems that utilize no tillage in the northern USA.

The objective of this study is to assess the influence of residue management in no tillage, continuous corn production systems on soil temperature, soil water content, and depth and duration of soil frost and snow cover during winter.

2. Materials and methods

This study was conducted in west central Minnesota, near Morris, on a Barnes loam (Udic Haploboroll) with a 2% east slope. The experimental site was in no-till corn production for the previous five years. West central Minnesota is characterized by a continental climate with a mean annual temperature of 5.5°C. Minimum daily air temperatures are typically below 0°C from 25 October to 15 April and snow cover persists from 1 December to 25 March.

Residue management treatments were established following corn harvest with a picker-sheller in October for three consecutive years beginning in 1987. The treatments were: (1) removal of stubble and loose residue (RR) from the soil surface using a flail chopper; (2) all residue lying prostrate (PR) on the soil surface, with stubble and loose residue chopped and blown back onto the soil surface using a flail chopper; and (3) stubble standing and loose residue lying (SR) on the soil surface as left by the picker-sheller. Treatments were arranged in a randomized block design with five replications. Soil disturbance on the 12×18 m individual plots was restricted to that occurring during corn planting in early May.

Instruments were installed in October to assess soil water content, soil temperature, frost depth, and snow cover. These instruments were monitored from 1 November (initiation of soil freezing) to late April (complete thaw of the soil profile). Soil water content was measured weekly at depths of 0.15, 0.45, 0.75, 1.05, and 1.35 m by neutron attenuation. Neutron access tubes were installed to a depth of 1.5 m at two locations in each plot. Soil temperatures were measured at depths of 0.05, 0.15, and 0.30 m using thermocouples. Three thermocouples were wired in parallel to give an average temperature for each depth. Air temperature was measured 1.2 m above the soil surface in each plot using a shielded thermocouple. Temperatures were measured every 60 s and averaged hourly by a data logger. Soil frost depth and snow cover measurements were taken weekly during the winter and daily during spring thaw. Soil frost depth was measured with CRREL frost tubes (Ricard et al., 1976) installed adjacent to each neutron tube to a depth of 1.5 m. An above-ground extension of the frost tube was used to measure snow cover.

Corn stubble height and residue weight as well as percent surface cover were measured after harvest. Stubble height was 0.07 m for the PR treatment and 0.35 m for the SR treatment. Total residue dry weight was 7.5 Mg ha^{-1} whereas percent residue cover determined by the line-transect method was 29% for the PR and SR treatments.

An Analysis of Variance and Tukey's Honestly Significant Difference (HSD) test were performed to determine differences in soil water content, soil temperature, soil frost depth, and snow cover.

3. Results and discussion

The prevailing climate each winter (October–April) did not typify the 100-year average in air temperature (−3.1°C) and snowfall (0.96 m). The 1989–1990 winter was warmer (−2.1°C) and drier (0.87 m snowfall) while the 1988–1989 winter was colder (−3.3°C) and wetter (1.38 m snowfall) than average. The winter of 1987–1988 was warm (−2.9°C) and dry (0.74 m snowfall). Monthly air temperature departures from the 100-year average ranged from 4.4°C colder in December 1989 to 7.7°C warmer in January 1990. Departures in snowfall from the 100-year average ranged from 0.15 m less in January 1990 to 0.21 m more in March 1989.

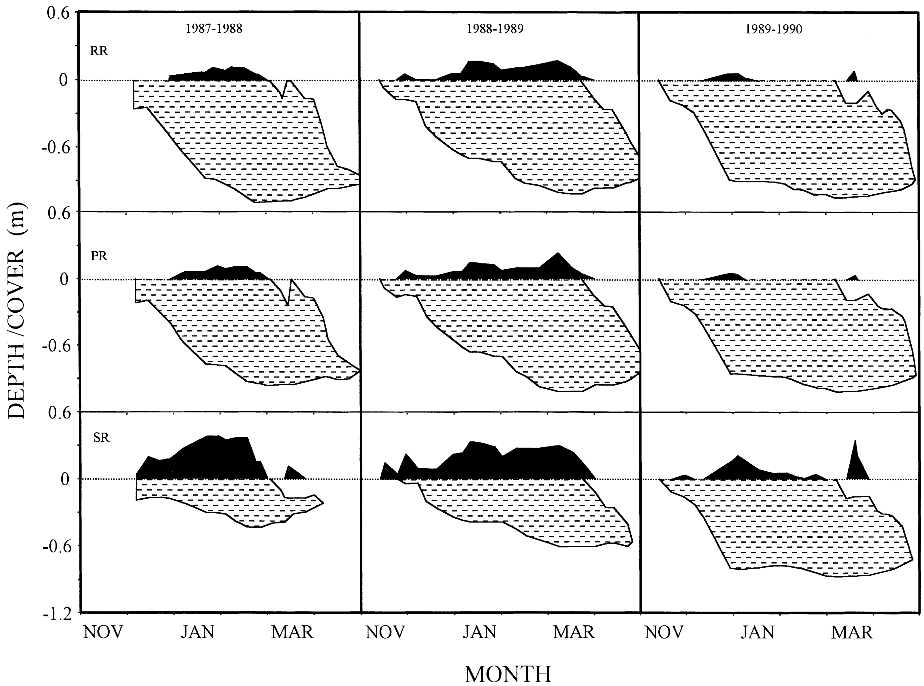

Fig. 1. Snow cover (solid pattern) and depth of frozen soil (dashed pattern) for a Barnes loam without corn residue (RR), with prostrate residue (PR), or with standing residue (SR) on the surface during three winters in Minnesota.

Corn residue management treatments caused differences in snow cover in all years (Fig. 1). Snow was deepest for the SR treatment compared with the RR and PR treatments. On a single winter day, snow cover for the SR treatment exceeded that of the RR and PR treatments by as much as 0.33 m during 1987–1988, 0.18 m during 1988–1989, and 0.26 m during 1989–1990. Snow cover was similar for the RR and PR treatments despite these treatments differing in residue dry weights and percent residue cover. The taller stubble on the SR treatment plots apparently reduced surface wind velocity that aided in retaining or trapping snow to a greater depth compared with the RR and PR treatments. Averaged across years, snow cover at the time of maximum frost penetration was 0.25 m for the SR treatment and about 0.07 m for the RR and PR treatments. Differences in snow cover may have been amplified by the use of small treatment plots in this study. Drifting of snow caused by the application of treatments is more likely to occur on small plots than within a uniformly treated field.

Maximum depth of soil freezing varied little across years despite the large differences in winter air temperatures and snowfall. Averaged across residue treatments, depth of maximum frost penetration was 0.96 m during the 1989–1990 winter while maximum frost depth was about 0.84 m during the two previous winters. The winter of 1989–1990 was 1.0°C warmer than average; however, the small snowfall that year resulted in a shallow snow pack (Fig. 1) and deeper frost penetration compared with previous years. Corn residue treatments influenced the depth of soil frost penetration. Averaged across years, the maximum depth of soil frost was 0.62 m for the SR treatment and 1.00 m for the RR and PR treatments. Residue treatments, however, had little influence on the time of maximum frost penetration during the winter. Instead, time of maximum frost penetration appeared to depend on air temperature and snow cover dynamics during the winter. Maximum frost penetration occurred in late February during the winter of 1987–88, but not until mid-March in succeeding winters (Fig. 1).

The rate of soil freezing during fall, maximum depth of soil frost, and rate of soil thawing during spring were influenced by the timing of cold or warm air masses and snowfall events along with the snow trapping capacity of residue treatments (Fig. 1). Snow cover was similar for the RR and PR treatments each winter, thus the rate of soil freezing and thawing as well as depth of frost penetration were nearly identical for these residue treatments. In comparison, frost depth characteristics for the SR treatment were markedly different from those of the RR and PR treatments each winter. The rapidity of soil freezing and thawing caused by the occurrence or duration of cold and warm air masses was dampened with the SR treatment due to the additional insulation provided by the thicker snow pack as compared with the RR and PR treatments. For example, from 15–31 December 1987 and 15–25 November 1988, little frost penetrated the soil profile in the SR treatment plot while the rate of soil frost penetration was nearly 0.02 m d^{-1} in the RR and PR treatment plots in both years (Fig. 1).

The amount of water in the upper 1.5 m of the soil profile differed throughout the winter as a result of residue treatments (Fig. 2). At the time of maximum frost penetration during the 1988–1989 and 1989–1990 winter, there was less water in the soil profile of the PR treatment plot than the RR or SR treatment plots (Table 1). The PR treatment apparently minimized the recharge of soil water, particularly during the fall of 1988 and 1989 when differences in soil water content first became apparent among treatments. The smaller recharge of soil water with the PR treatment may be due to a thinner snowpack compared with the SR treatment or to greater interception and storage of water in the residue canopy compared with the RR treatment. Differences in soil water recharge due to treatments were apparent in early December 1988 and 1989 when snowmelt on the SR treatment plot induced a larger rise in soil water than in the PR treatment plot (Fig. 2). These differences in soil water content then persisted through the winter. Soil water contained in the 1.5 m profile also increased during periods of snowmelt in the spring. For example, the increase in soil water during March 1988 and 1989 (Fig. 2) coincides with snowmelt events (Fig. 1). The increase in soil water in April 1988 resulted from rain.

Air temperatures from November to March were lowest (−7.0°C) for the 1988–1989 winter and highest (−6.0°C) for the 1989–1990 winter. Soil temperatures for the 0.05–0.30 m depth, however, were lowest (−3.5°C) during the 1987–1988 winter and highest (−2.0°C) for the 1988–1989 winter. Although air temperatures were coldest during the 1988–1989 winter, snowfall during the 1988–1989 winter exceeded that of other winters by at least 0.50 m. The early and

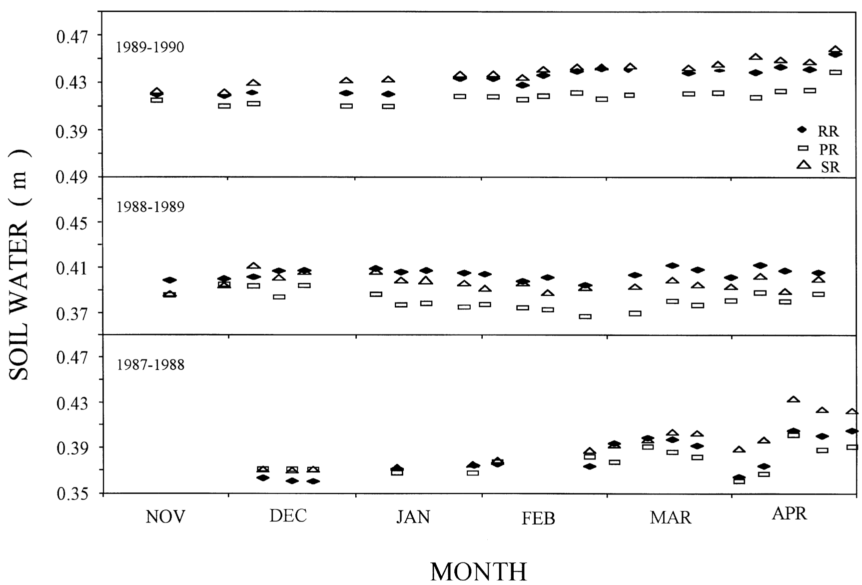

Fig. 2. The amount of water in the top 1.5 m of a Barnes loam without surface corn residue (RR), with prostrate residue (PR), or with standing residue (SR) during three winters in Minnesota.

Table 1
Soil water (m) in a Barnes loam profile subject to three corn residue management treatments near Morris, MN (soil water was assessed to 1.5 m depth at the time of maximum frost penetration over three winters)

Residue treatment	1987–1988	1988–1989	1989–1990
No residue	0.375 a	0.415 a	0.440 a
Prostrate residue	0.385 a	0.380 b	0.420 b
Standing residue	0.390 a	0.400 ab	0.445 a

Means for a residue treatment followed by a common letter are not significantly different ($P \leq 0.05$) based on Tukey's Honestly Significant Difference test.

deep snow cover during the 1988–1989 winter (Fig. 1) insulated the soil and thus moderated soil temperatures. The greater range in soil (1.5°C) versus air (1.0°C) temperatures across winters also attests to the variability in snow or surface cover causing large soil temperature differences across years.

Winter soil temperatures were consistently warmer for the SR treatment as compared with the RR or PR treatments across years (Fig. 3). Little difference in soil temperatures was noted between the RR and PR treatments. Corn residue treatments significantly (P=0.05) affected soil temperatures from the time of snow cover in the fall to snowmelt in the spring. Differences in soil temperatures were consistent during winter, but were not always significant when analyzed within a year or by measurement depth. Within any one year, temperature differences due to residue treatments were largest during cold periods and smallest during warm periods. In addition, differences in winter soil temperatures due to treatments were accentuated in years when snowfall or snow redistribution by wind caused large differences in snow cover among treatments. Residue treatments did not influence soil temperatures before snow accumulation in the fall or after snowmelt in the spring.

4. Conclusions

Corn residue management in the north central USA can impact the winter soil thermal regime. Residue

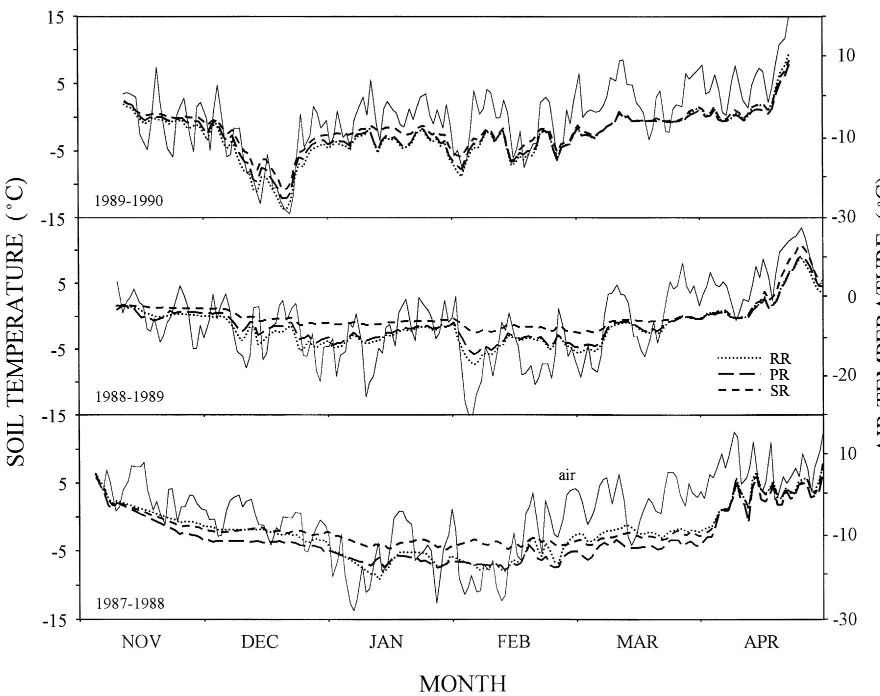

Fig. 3. Daily air and soil (0.05–0.30 m depth) temperatures of a Barnes loam without surface corn residue (RR), with prostrate residue (PR), or with standing residue (SR) during three winters in Minnesota.

management practices that retain stubble on the soil surface will promote deeper and longer snow cover, higher soil temperatures, and shallower frost penetration as compared with practices that chop the stubble or remove all residue from the soil surface. Therefore, in windy regions where snow is redistributed by wind, stubble that remains standing in the field after harvest will trap or retain snow and thus promote earlier soil thawing and possibly earlier planting in the spring.

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